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Design and Analysis of Autonomous Mobile Robot

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Abstract

The automation sector's rise is astounding, and its ongoing expansion has given new vitality to the previous outdated industries. The utilization of Autonomous robots has lowered the human burden, allowing it to be more efficiently employed for more gratifying jobs. The main motive of the project is to design, analyze and fabricate an autonomous mobile robot that has a payload of 30 kg. This robot can be used in the warehouse automation material handling industry. By implementing this autonomous mobile robot the productivity, time, and cost of the process can be reduced. The autonomous mobile robot is designed in such a way that it can withstand a high amount of load when applied to the frame of the robot. The modeling of the robot is done in SolidWorks software and the autonomous navigation is done by the Robot operating software (ROS). The design analysis was done in the ANSYS software. Finally, the robot is fabricated and tested with a 30 kg payload.

Keywords*—Robot operating system, Autonomous navigation, Material handling, Structural analysis.*

I. INTRODUCTION

An Autonomous Mobile Robot (AMR) is any robot that can comprehend and navigate its environment without being directly overseen by a human or following a preset path. AMRs are equipped with a variety of sophisticated sensors that let them to learn and understand their environment, allowing them to do their jobs in the most efficient and course-planning way possible, while navigating around fixed and variable obstacles. Autonomous mobile robots seek the most efficient way to accomplish each activity and are designed to work with people in jobs like picking and sorting.

A. *Problem Statement*

AMRs are required at a warehouse to carry goods weighing 30 kg with care. To improve the efficiency and productivity of processes and workflows above human laborites advanced technologies are linked with the warehouse's management systems in a warehouse and distribution center environment, giving AMRs more freedom to establish their own routes between sites inside a warehouse or facility.

B. *Objectives of the Project*

The project's major goal is to use AMRs to provide a simple, cost-effective, and efficient approach to automate material handling and in-house transportation duties in practically every circumstance where workers were previously required to move the carts throughout the plant.

II. LITERATURE SURVEY

A. *Literature Review*

Michael Shneier, et al [1], presented an overview of mobile robots aimed towards industrial applications It explains the many types of mobile robots that are utilised and the criteria that should be considered when determining whether or not to employ mobile robots. It also discusses methods for localising and directing robots, as well as their safe usage in collaborative applications with people.

A. A. A. Razak et al [2], showed how to build, develop, and simulate a mobile robot structure for a specific task. The mobile robot is built with a four-wheel drive system that allows for quick and sharp turns. The rectangular structure of the robot is made of mild steel square pipes. The tension and displacement of the structure are analyzed using simulation. The examination of the data shows that the construction is acceptable for usage in restricted spaces.

E. Vijayaragavan et al [3], has created and tested a mobile robot for a material handling system, the robot's goal is to translate lengthy racks in storage homes to other places. The lead screw mechanism was utilized to raise the racks, and a differential drive for movement of the robot. CATIA and ANSYS were used to design and analyze the robot, respectively.

K. Shabalina et al [4], discussed the factors to consider while developing a wheeled mobile robot platform. The article helps in examining the best type of mobile robot configuration like holonomic or non-holonomic which can be used to while carrying a payload

R. Shah et al [5], has suggested a novel mobile robot design that may be utilized for military, rescue, and industrial purposes. The major constraint in robot design is height, although this may be solved by utilizing powerful hydraulic and pneumatic systems. Spiral lift mechanism is used here to lift heavy loads.

B. *Outcome of the Literature Review*

The literature survey has bought effective results and has helped in understanding the requirements clearly. The outcome includes different types and applications of mobile robots used in the industries, Considerations while designing a mobile robot and Stress analysis on Mobile robot design.

C. *Patent Search*

Autonomous Mobile Robot (US 20150197012A1)

A robot body, a driving system, a sensor system, and a controller comprise an autonomous mobile robot. The driving system both supports the robot's body and moves it across a floor surface. The sensor system contains an inertial measurement unit for measuring the robot's attitude and emitting a sensor signal containing data including information about the robot's pose. The controller interfaces with the driving and sensor systems, as well as running a behaviour system. The sensor signal is received by the behaviour system, which then conducts a behaviour. In response to sensor data suggesting that the robot is limited to assess, the behaviour system conducts an anti-stasis behaviour.

Intelligent autonomous wheel type mobile robot (CN100493858C)

The camera for providing ambient information, industrial control computer capable of communicating via CAN bus to motor driver/controller, ultrasonic ring and infrared ring, and the moving mechanism controlled by motor driver/controller comprise an autonomous wheel type movable intelligent robot with such functions as dynamic target tracking, target recognition, and man-machine interaction by speed. Ultrasonic, infrared, and optical sensors are employed.

III. METHODOLOGY

The methodology starts with choosing the mobile robot configuration that is holonomic or non-holonomic and how many wheels to use based on the application. Next, the type of wheel is chosen according to the previous step. And then based on the overall weight of the robot which includes a payload and other components assumed loads, the motor sizing is done. Then the selection of drives, sensors, computers, and communication buses for interfacing them is done. The overall power consumption for the electronic devices is calculated and then the battery power capacity is selected. After the end of components selection, the cad modelling of the overall robot is done using SOLIDWORKS software. And finally, the structural analysis of the designed robot is simulated to check whether the structure can withstand the combination of overall Robot weight and 30 kg payload.

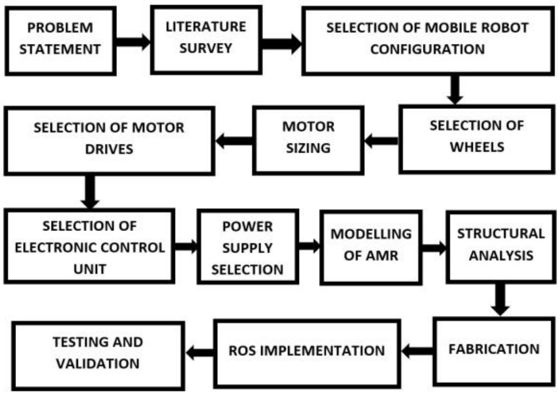

Fig 1. Methodology flowchart

IV. HARDWARE DESCRIPTION

A. *Design of the Chassis*

The robot chassis as shown in Fig 2 is a metallic frame that supports and holds both the electronics and mechanism which drives the robot. It serves as the robot's foundation and is in charge of handling the stress caused by the robot's input load. It is the structure's responsibility to deal with the various forces encountered by the robot. It's also where the drive motor and wheels are housed.

Fig 2. CAD Model of the Robot

B. *Material of the Chassis*

The chassis of a robot can be constructed from a variety of traditional materials. The chassis specifications are used to choose an appropriate material. Mild steel, also known as "low carbon steel," is a low carbon content carbon steel. A material's load bearing capacity can be increased by designing the chassis and the supporting structures in a specific shape. It is both affordable and widely available. It is chosen as the construction material for the above-mentioned mild steel properties

C. *Shape of the Chassis*

The geometry of a chassis is a crucial aspect that can boost a material's strength to carry load. Conventional robot chassis geometry include squares, rectangles, and so on. A Trapezoid prism on a cuboid shaped chassis as shown in Fig 3 has been applied to this robot. Fillets can be used to smooth out any sharp corners on the Trapezoid prism's edges. Sharp corners are known to concentrate or accumulate stress, so rounded corners are preferable.

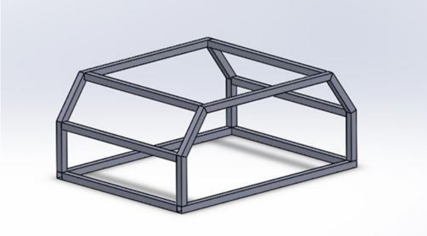

Fig 3. Mild Steel Chassis

D. *Drive of the Chassis*

The application of the robot determines the utilization of the type of drive configuration. In this mobile robot, as illustrated in Fig 4, a differential electric drive is employed. The four castor wheels and two driving wheels are symmetrically positioned. The thrust bearing in the castor wheels allows the weight on the driving wheels to be reduced.

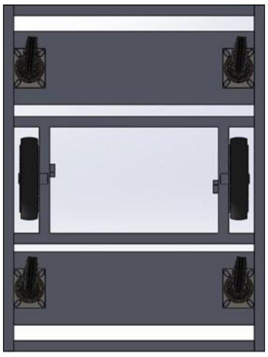

Fig 4. Differential Drive Arrangement

The robot must move slowly in order to balance the payload. For good friction between the surface and the wheels, the wheels are coated with rubber. Robotic drive wheels are best suited to silicone based rubber. Nylon is used as the core material because it is less dense and has better vibration dampening properties than metals.

Circular ball bearings are used to support the motor shaft to withstand the payload and also the structural load. Since gear coupling can cause backlash, the motors shafts are directly coupled to the wheels.

E. *Sensor*

RPLIDAR A1 as shown in Fig 5 is based on the laser triangulation ranging technology. It can collect distance data at a rate of over 8000 times per second. RPLIDAR spins clockwise to provide 360 degree sensor data. The gathered data is sent to the slam software to output a map.

Fig 5. RP-LIDAR

F. *Actuators and Driver*

The vehicle wiper motor as shown in Fig 6 is the component that drives the wipers on the windshield. A mechanism incorporated within it moves a worm gear, arm, and, lastly, the windshield or windscreen wiper blades as it revolves. The wiper motors were chosen because they had higher torque. Its shaft is directly coupled to the AMR drive wheels.

Fig 6. Wiper Motor

The MD20A as shown in Fig 7 provides bidirectional control of a single high-power brushed DC motor ranging in voltage from 6V to 30V. This motor driver can sustain 20Amp constantly without a heatsink thanks to its discrete NMOS H-Bridge architecture.

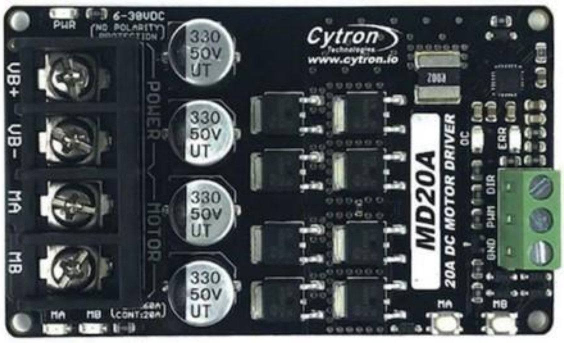

Fig 7. MD20A Motor Driver

G. Processors and Controlllers

The Arduino Mega is a microcontroller board. It features 54 digital Input /Output pins where 14 are PWM outputs, and 16 analog inputs as shown in Fig 8. Arduino Mega is used in this project as it has more memory to store the ROS header files and also the number of PWM ports are more when compared with the previous versions.

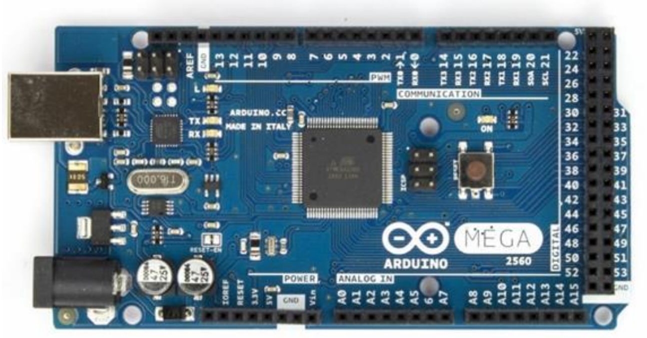

Fig 8. Arduino Mega

The Raspberry Pi® 4 is a popular small-sized computing system. Raspberry Pi 4 is equipped with a high-performance and low powered ARM Cortex quad core CPU as shown in Fig 9. It is equipped with WIFI antenna, bluetooth and Ethernet for communication. Raspberry Pi can be loaded with Ubuntu software to support the Robot operating system software for autonomous navigation.

Fig 9. Raspberry Pi 4

V. STRUCTURAL ANALYSIS

The structural study of the robot is crucial in the development process. It gives quantifiable information on the amounts of stress and strain encountered by the AMR as a result of the payload. The analysis was carried out using the analytical software ANSYS. At first, the 3D CAD Model which was created in Solid Works is imported in the ANSYS as shown in Fig 10.

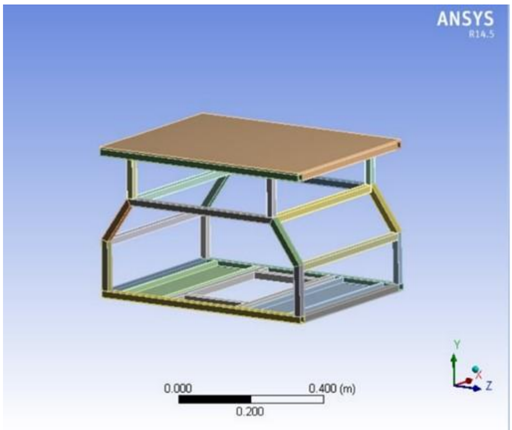

Fig 10. Importing Model in ANSYS

The next step is to apply mild steel material to the structure. After the previous step, the structure is divided into small symmetrical shapes which is known as meshing. Meshing gives the exact details of where the deformation occurs so it is an important step.

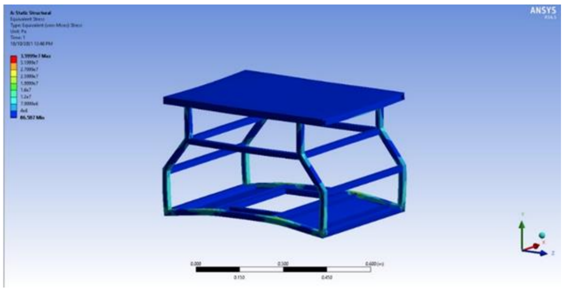

Fig 11. Chart of Von-Mises Stress

On the platform, a distributed load of 300 N is applied. The robot's base is fixed to perform static structural analysis. The structure is then studied with Von-Mises stress.

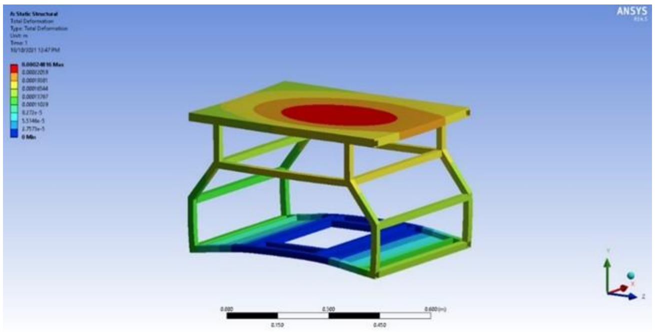

Fig 12. Maximum deformation

The Maximum working stress and Total deformation is found to be 35.999 MPa and 0.00024816 m respectively as shown in Fig 11 and 12. Ultimate yield strength of Mild Steel is 460 MPa.

The Maximum deformation is very low. Maximum working stress is less than Ultimate yield strength of Mild Steel. As a result, the design is regarded as secure.

VI. ROS IMPLENTATION

A. *URDF Conversion*

The Unified Robotic Description Format (URDF) is an XML file format used in ROS to define all of a robot's components. We can use URDF to describe a robot model, sensors, joints, link, collision matrix and visual looks. The URDF file is generated using SolidWorks URDF Exporter.

After exporting the URDF, the file should be verified whether it doesn't contain any errors by visualizing the model in ROS RVIZ environment as shown in Fig 13.

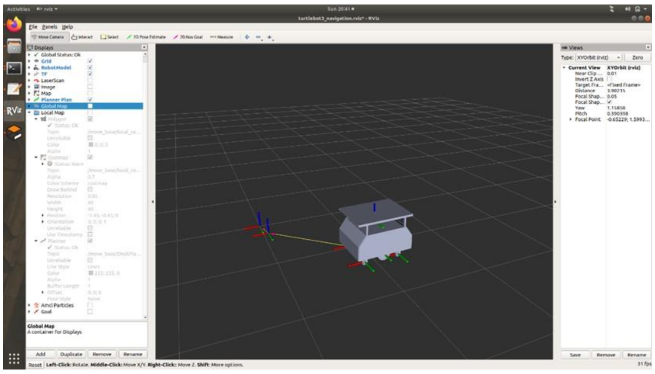

Fig 13. RViz visualization

B. *ROS Plugins*

The ROS system has a plugin framework called plugin lib that allows us to dynamically load and unload plugins, which can be libraries or classes. The plugin lib is a C++ library set those aids in the creation of plugins and their loading and unloading as needed. Plugin files are runtime libraries that are built without connecting to the main program code, such as shared object or dynamic link libraries. Plugins are independent entities that do not rely on the main program. The major advantage of plugins is that they allow us to increase the program's capabilities without requiring significant modifications to the core application code. In this project LIDAR sensor plugin was used to simulate the laser scan in ROS Gazebo as shown in Fig 14.

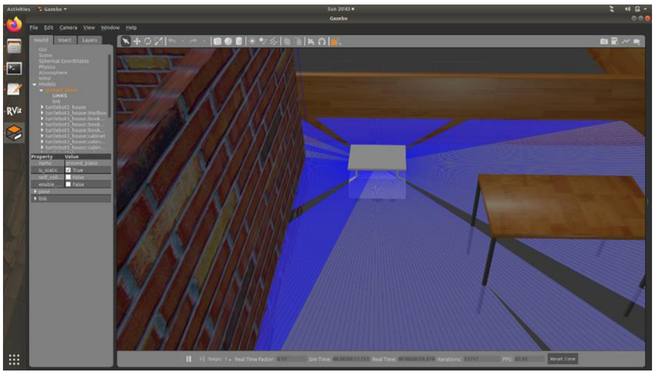

Fig 14. Visualization of laser in Gazebo

C. Google Cartographer

Cartographer is a real-time simultaneous localization and mapping (SLAM) system that works across different platforms and sensor combinations to offer SLAM in 2D and 3D. Cartographer can create an environment map and indicate where the robot is in relation to the map. Cartographers may create maps in both 2D and 3D. However, for a 3D map, point cloud as a source is required. Cartographer SLAM doesn't require an IMU or an encoder to produce Odometery value of the robot, as it can produce its own Odom value using the Laser Scan data itself.

D. Navigation

The Navigation Stack gathers Odometry and laser range data from encoders and laser sensors, respectively as shown in Fig 15. Following computation, it outputs velocity data to the move-base node under the topic command velocity. Both differential and omnidirectional robots can benefit from a navigation stack. It necessitates the installation of a laser sensor on the mobile base. This laser sensor is uitilised for localization and mapping. Because it was designed for square or circular shaped robots, the Navigation Stack cannot be used on random shaped robots.

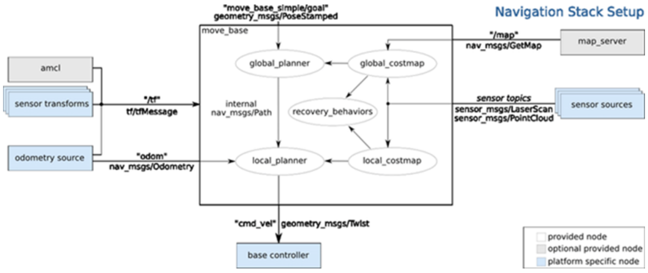

Fig 15. Overview of Navigation Stack

It employs a global cost map and a global planner to plan a route to a goal location using a preloaded map, as well as a local cost map and a local planner for dynamic obstacle avoidance. Because the robot in the simulation is non-holonomic, the AMCL parameters must be modified to non-holonomic configurations, and Y-axis velocity must be removed from the local planner parameters.

VII. RESULT AND ANALYSIS

After the conversion of Solid Works part file to URDF, the mobile robot was assigned many tasks to evaluate its ability to fulfil specified duties. The robot was generated in the gazebo world environment, which contains random class objects. Initially a map was created using google cartographer as shown in Fig 16.

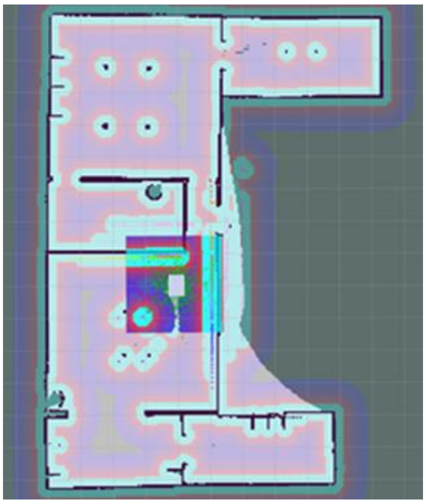

Fig 16. Google cartographer mapping

The robot has successfully travelled and produced a map of an environment. Using the generated map, the navigation stack converts that into global cost map.

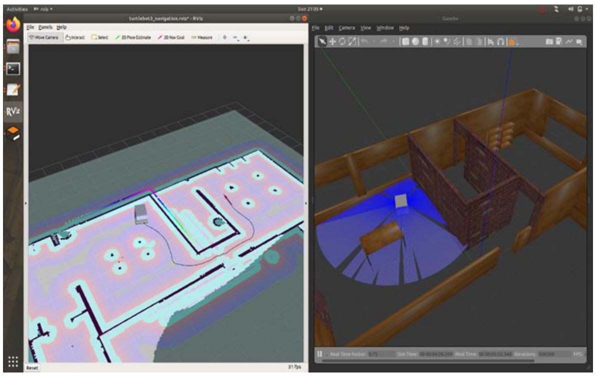

Fig 17. Global path planning of the robot

Several waypoints were marked in the map for the mobile robot to navigate to that position and evaluate its performance. Finally, after the simulation the results were found to be promising as the robot autonomously avoided obstacle and navigated to its goal point as shown in Fig 17 with a goal point tolerance of xy_goal_tolerance: 0.04 and yaw_goal_tolerance: 0.15.

After the structural analysis done by ANSYS Software. It was found that the maximum Von misses stress was less than the ultimate yield strength, so the model was found to be safe to carry 30 kg payload

As the design is considered to be safe, the hardware fabrication was done. The Mild steel square pipes are joined together by arc welding. The structural covering was done by attaching sheet metal onto it as shown in Fig 18. The sheet metal attached to the frame using bolts and can be removed easily if any maintenance work has to be done. Finally, ROS navigation software has been implemented in the robot and autonomous navigation was done.

Fig 18. Hardware

VIII. CONCLUSION

In this project, we designed, analyzed and fabricated an Autonomous mobile Robot which is capable of carrying a payload of 30 kg. The projects show the ways of designing a mobile robot by considering some design parameters and simulating it to find whether the model is safe to fabricate. After the fabrication is done, ROS software was implemented and the autonomous navigation was done successfully. This robot can be used in Logistics warehouses where humans and robots can work collaboratively which can help in the movement of materials within the warehouse efficiently

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